Índice

1. algorithm

#include <algorithm> #include <numeric>

Algo	Params	Funcion
sort, stable_sort	f, l	ordena el intervalo
nth_element	f, nth, l	*void* ordena el n-esimo, y particiona el resto
fill, fill_n	f, l / n, elem	*void* llena [f, l) o [f, f+n) con elem
lower_bound, upper_bound	f, l, elem	*it* al primer / ultimo donde se puede insertar elem para que quede ordenada
binary_search	f, l, elem	*bool* esta elem en [f, l)
copy	f, l, resul	hace resul+i=f+i $\forall i$
find, find_if, find_first_of	f, l, elem / pred / f2, l2	*it* encuentra i $\in$[f,l) tq. i=elem, pred(i), i$\in$[f2,l2)
count, count_if	f, l, elem/pred	cuenta elem, pred(i)
search	f, l, f2, l2	busca [f2,l2) $\in$ [f,l)
replace, replace_if	f, l, old / pred, new	cambia old / pred(i) por new
reverse	f, l	da vuelta
partition, stable_partition	f, l, pred	pred(i) ad, !pred(i) atras
min_element, max_element	f, l, [comp]	*it* min, max de [f,l)
lexicographical_compare	f1,l1,f2,l2	*bool* con [f1,l1)¡[f2,l2)
next/prev_permutation	f,l	deja en [f,l) la perm sig, ant
set_intersection, set_difference, set_union, set_symmetric_difference,	f1, l1, f2, l2, res	[res, . . .) la op. de conj
push_heap, pop_heap, make_heap	f, l, e / e /	mete/saca e en heap [f,l), hace un heap de [f,l)
is_heap	f,l	*bool* es [f,l) un heap
accumulate	f,l,i,[op]	$T = \sum$/oper de [f,l)
inner_product	f1, l1, f2, i	T = i + [f1, l1) . [f2, . . .)
partial_sum	f, l, r, [op]	r+i = $\sum$/oper de [f,f+i] $\forall i \in$[f,l)
__builtin_ffs	unsigned int	Pos. del primer 1 desde la derecha
__builtin_clz	unsigned int	Cant. de ceros desde la izquierda.
__builtin_ctz	unsigned int	Cant. de ceros desde la derecha.
__builtin_popcount	unsigned int	Cant. de 1's en x.
__builtin_parity	unsigned int	1 si x es par, 0 si es impar.
__builtin_XXXXXXll	unsigned ll	= pero para long long's.

2.   Estructuras

2.1.   RMQ (static)

Dado un arreglo y una operación asociativa *idempotente*, get(i, j) opera sobre el rango [i, j). Restricción: LVL ≥ ceil(logn); Usar [ ] para llenar arreglo y luego build().

```
struct RMQ{
  #define LVL 10
  tipo vec[LVL][1<<(LVL+1)];
  tipo &operator[](int p){return vec[0][p];}
  tipo get(int i, int j) {//intervalo [i,j)
    int p = 31-__builtin_clz(j-i);
    return min(vec[p][i],vec[p][j-(1<<p)]);
  }
  void build(int n) {//O(nlogn)
    int mp = 31-__builtin_clz(n);
    forn(p, mp) forn(x, n-(1<<p))
      vec[p+1][x] = min(vec[p][x], vec[p][x+(1<<p)]);
  }
};
```

2.2.   RMQ (dynamic)

```
//Dado un arreglo y una operacion asociativa con neutro, get(i, j) opera
    sobre el rango [i, j).
#define MAXN 100000
#define operacion(x, y) max(x, y)
const int neutro=0;
struct RMQ{
  int sz;
  tipo t[4*MAXN];
  tipo &operator[](int p){return t[sz+p];}
  void init(int n){//O(nlgn)
    sz = 1 << (32-__builtin_clz(n));
    forr(i, sz, 2*sz) t[i]=neutro;
  }
  void updall(){//O(n)
    dforn(i, sz) t[i]=operacion(t[2*i], t[2*i+1]);}
  tipo get(int i, int j){return get(i,j,1,0,sz);}
  tipo get(int i, int j, int n, int a, int b){//O(lgn)
    if(j<=a || i>=b) return neutro;
    if(i<=a && b<=j) return t[n];
```

```
    int c=(a+b)/2;
    return operacion(get(i, j, 2*n, a, c), get(i, j, 2*n+1, c, b));
  }
  void set(int p, tipo val){//O(lgn)
    for(p+=sz; p>0 && t[p]!=val;){
      t[p]=val;
      p/=2;
      val=operacion(t[p*2], t[p*2+1]);
    }
  }
}rmq;
//Usage:
cin >> n; rmq.init(n); forn(i, n) cin >> rmq[i]; rmq.updall();
```

2.3.   RMQ (lazy)

```
//Dado un arreglo y una operacion asociativa con neutro, get(i, j) opera
    sobre el rango [i, j).
typedef int Elem;//Elem de los elementos del arreglo
typedef int Alt;//Elem de la alteracion
#define operacion(x,y) x+y
const Elem neutro=0; const Alt neutro2=0;
#define MAXN 100000
struct RMQ{
  int sz;
  Elem t[4*MAXN];
  Alt dirty[4*MAXN];//las alteraciones pueden ser de distinto Elem
  Elem &operator[](int p){return t[sz+p];}
  void init(int n){//O(nlgn)
    sz = 1 << (32-__builtin_clz(n));
    forr(i, sz, 2*sz) t[i]=neutro;
    forn(i, 2*sz) dirty[i]=neutro2;
  }
  void push(int n, int a, int b){//propaga el dirty a sus hijos
    if(dirty[n]!=0){
      t[n]+=dirty[n]*(b-a);//altera el nodo
      if(n<sz){
        dirty[2*n]+=dirty[n];
        dirty[2*n+1]+=dirty[n];
      }
      dirty[n]=0;
    }
  }
```

```
27    Elem get(int i, int j, int n, int a, int b){//O(lgn)
28      if(j<=a || i>=b) return neutro;
29      push(n, a, b);//corrige el valor antes de usarlo
30      if(i<=a && b<=j) return t[n];
31      int c=(a+b)/2;
32      return operacion(get(i, j, 2*n, a, c), get(i, j, 2*n+1, c, b));
33    }
34    Elem get(int i, int j){return get(i,j,1,0,sz);}
35    //altera los valores en [i, j) con una alteracion de val
36    void alterar(Alt val, int i, int j, int n, int a, int b){//O(lgn)
37      push(n, a, b);
38      if(j<=a || i>=b) return;
39      if(i<=a && b<=j){
40        dirty[n]+=val;
41        push(n, a, b);
42        return;
43      }
44      int c=(a+b)/2;
45      alterar(val, i, j, 2*n, a, c), alterar(val, i, j, 2*n+1, c, b);
46      t[n]=operacion(t[2*n], t[2*n+1]);//por esto es el push de arriba
47    }
48    void alterar(Alt val, int i, int j){alterar(val,i,j,1,0,sz);}
49  }rmq;
```

2.4.   Fenwick Tree

```
1  //For 2D threat each column as a Fenwick tree, by adding a nested for in
       each operation
2  struct Fenwick{
3    static const int sz=1000001;
4    tipo t[sz];
5    void adjust(int p, tipo v){//valid with p in [1, sz), O(lgn)
6      for(; p<sz; p+=(p&-p)) t[p]+=v; }
7    tipo sum(int p){//cumulative sum in [1, p], O(lgn)
8      tipo s=0;
9      for(; p; p-=(p&-p)) s+=t[p];
10     return s;
11   }
12   tipo sum(int a, int b){return sum(b)-sum(a-1);}
13   //get largest value with cumulative sum less than or equal to x;
14   //for smallest, pass x-1 and add 1 to result
15   int getind(tipo x) {//O(lgn)
16     int idx = 0, mask = N;
```

```
17     while(mask && idx < N) {
18       int t = idx + mask;
19     if(x >= tree[t])
20         idx = t, x -= tree[t];
21       mask >>= 1;
22     }
23     return idx;
24   }
25  };
```

2.5.   Union Find

```
1  struct UnionFind{
2    vector<int> f;//the array contains the parent of each node
3    void init(int n){f.clear(); f.insert(f.begin(), n, -1);}
4    int comp(int x){return (f[x]==-1?x:f[x]=comp(f[x]));}//O(1)
5    bool join(int i, int j) {
6      bool con=comp(i)==comp(j);
7      if(!con) f[comp(i)] = comp(j);
8      return con;
9    }
10  };
```

2.6.   Disjoint Intervals

```
1  bool operator< (const ii &a, const ii &b) {return a.fst<b.fst;}
2  //Stores intervals as [first, second]
3  //in case of a collision it joins them in a single interval
4  struct disjoint_intervals {
5    set<ii> segs;
6    void insert(ii v) {//O(lgn)
7      if(v.snd-v.fst==0.) return;//OJO
8      set<ii>::iterator it,at;
9      at = it = segs.lower_bound(v);
10     if (at!=segs.begin() && (--at)->snd >= v.fst)
11       v.fst = at->fst, --it;
12     for(; it!=segs.end() && it->fst <= v.snd; segs.erase(it++))
13       v.snd=max(v.snd, it->snd);
14     segs.insert(v);
15   }
16  };
```

2.7.   RMQ (2D)

```
1  struct RMQ2D{
2    static const int sz=1024;
3    RMQ t[sz];
4    RMQ &operator[](int p){return t[sz/2+p];}
5    void build(int n, int m){//O(nm)
6      forr(y, sz/2, sz/2+m)
7        t[y].build(m);
8      forr(y, sz/2+m, sz)
9        forn(x, sz)
10         t[y].t[x]=0;
11     dforn(y, sz/2)
12       forn(x, sz)
13         t[y].t[x]=max(t[y*2].t[x], t[y*2+1].t[x]);
14   }
15   void set(int x, int y, tipo v){//O(lgm.lgn)
16     y+=sz/2;
17     t[y].set(x, v);
18     while(y/=2)
19       t[y].set(x, max(t[y*2][x], t[y*2+1][x]));
20   }
21   //O(lgm.lgn)
22   int get(int x1, int y1, int x2, int y2, int n=1, int a=0, int b=sz/2){
23     if(y2<=a || y1>=b) return 0;
24     if(y1<=a && b<=y2) return t[n].get(x1, x2);
25     int c=(a+b)/2;
26     return max(get(x1, y1, x2, y2, 2*n, a, c),
27           get(x1, y1, x2, y2, 2*n+1, c, b));
28   }
29 };
30 //Example to initialize a grid of M rows and N columns:
31 RMQ2D rmq;
32 forn(i, M)
33   forn(j, N)
34     cin >> rmq[i][j];
35 rmq.build(N, M);
```

2.8. Big Int

```
1  #define BASEXP 6
2  #define BASE 1000000
3  #define LMAX 1000
4  struct bint{
5      int l;
6      ll n[LMAX];
7      bint(ll x=0){
8          l=0;
9          forn(i, LMAX){
10             n[i]=x%BASE;
11             x/=BASE;
12             l+=!!x||!i;
13         }
14     }
15     bint(string x){
16     l=(x.size()-1)/BASEXP+1;
17         fill(n, n+LMAX, 0);
18         ll r=1;
19         forn(i, sz(x)){
20             n[i / BASEXP] += r * (x[x.size()-1-i]-'0');
21             r*=10; if(r==BASE)r=1;
22         }
23     }
24     void out(){
25     cout << n[l-1];
26     dforn(i, l-1) printf("%6.6llu", n[i]);//6=BASEXP!
27   }
28   void invar(){
29     fill(n+l, n+LMAX, 0);
30     while(l>1 && !n[l-1]) l--;
31   }
32 };
33 bint operator+(const bint&a, const bint&b){
34   bint c;
35     c.l = max(a.l, b.l);
36     ll q = 0;
37     forn(i, c.l) q += a.n[i]+b.n[i], c.n[i]=q %BASE, q/=BASE;
38     if(q) c.n[c.l++] = q;
39     c.invar();
40     return c;
41 }
42 pair<bint, bool> lresta(const bint& a, const bint& b)   // c = a - b
43 {
44   bint c;
45     c.l = max(a.l, b.l);
46     ll q = 0;
47     forn(i, c.l) q += a.n[i]-b.n[i], c.n[i]=(q+BASE) %BASE, q=(q+BASE)/
              BASE-1;
```

```
48      c.invar();
49      return make_pair(c, !q);
50  }
51  bint& operator-= (bint& a, const bint& b){return a=lresta(a, b).first;}
52  bint operator- (const bint&a, const bint&b){return lresta(a, b).first;}
53  bool operator< (const bint&a, const bint&b){return !lresta(a, b).second
        ;}
54  bool operator<= (const bint&a, const bint&b){return lresta(b, a).second
        ;}
55  bool operator==(const bint&a, const bint&b){return a <= b && b <= a;}
56  bint operator*(const bint&a, ll b){
57      bint c;
58      ll q = 0;
59      forn(i, a.l) q += a.n[i]*b, c.n[i] = q %BASE, q/=BASE;
60      c.l = a.l;
61      while(q) c.n[c.l++] = q %BASE, q/=BASE;
62      c.invar();
63      return c;
64  }
65  bint operator*(const bint&a, const bint&b){
66      bint c;
67      c.l = a.l+b.l;
68      fill(c.n, c.n+b.l, 0);
69      forn(i, a.l){
70          ll q = 0;
71          forn(j, b.l) q += a.n[i]*b.n[j]+c.n[i+j], c.n[i+j] = q %BASE, q
                /=BASE;
72          c.n[i+b.l] = q;
73      }
74      c.invar();
75      return c;
76  }
77  pair<bint, ll> ldiv(const bint& a, ll b){// c = a / b ; rm = a % b
78      bint c;
79      ll rm = 0;
80      dforn(i, a.l){
81              rm = rm * BASE + a.n[i];
82              c.n[i] = rm / b;
83              rm %= b;
84      }
85      c.l = a.l;
86      c.invar();
87      return make_pair(c, rm);
88  }
89  bint operator/(const bint&a, ll b){return ldiv(a, b).first;}
90  ll operator%(const bint&a, ll b){return ldiv(a, b).second;}
91  pair<bint, bint> ldiv(const bint& a, const bint& b){
92      bint c;
93      bint rm = 0;
94      dforn(i, a.l){
95          if (rm.l==1 && !rm.n[0])
96              rm.n[0] = a.n[i];
97          else{
98              dforn(j, rm.l) rm.n[j+1] = rm.n[j];
99              rm.n[0] = a.n[i];
100             rm.l++;
101         }
102         ll q = rm.n[b.l] * BASE + rm.n[b.l-1];
103         ll u = q / (b.n[b.l-1] + 1);
104         ll v = q /  b.n[b.l-1] + 1;
105         while (u < v-1){
106             ll m = (u+v)/2;
107             if (b*m <= rm) u = m;
108             else v = m;
109         }
110         c.n[i]=u;
111         rm-=b*u;
112     }
113     c.l=a.l;
114     c.invar();
115     return make_pair(c, rm);
116 }
117 bint operator/(const bint&a, const bint&b){return ldiv(a, b).first;}
118 bint operator%(const bint&a, const bint&b){return ldiv(a, b).second;}
```

2.9. Modnum

```
1  struct mnum{
2     static const tipo mod=12582917;
3     tipo v;
4     mnum(tipo v=0): v(v%mod) {}
5     mnum operator+(mnum b){return v+b.v;}
6     mnum operator-(mnum b){return v>=b.v? v-b.v : mod-b.v+v;}
7     mnum operator*(mnum b){return v*b.v;}
8     mnum operator^(int n){
9        if(!n) return 1;
```

```
10        return n%2? (*this)^(n/2)*(this) : (*this)^(n/2);}
11  };
```

2.10.   Treap

```
1   typedef int Key;
2
3   typedef struct node *pnode;
4   struct node{
5       Key key;
6       int prior, size;
7       pnode l,r;
8       node(Key key=0, int prior=0): key(key), prior(prior), size(1), l(0),
            r(0) {}
9   };
10  struct treap {
11      pnode root;
12      treap(): root(0) {}
13      int size(pnode p) { return p ? p->size : 0; }
14      int size() { return size(root); }
15      void push(pnode p) {
16          // modificar y propagar el dirty a los hijos aca(para lazy)
17      }
18      // Update function and size from children's values
19      void pull(pnode p) {//recalcular valor del nodo aca (para rmq)
20          p->size = 1 + size(p->l) + size(p->r);
21      }
22      pnode merge(pnode l, pnode r) {
23          if (!l || !r) return l ? l : r;
24          push(l), push(r);
25          pnode t;
26          if (l->prior < r->prior) l->r=merge(l->r, r), t = l;
27          else r->l=merge(l, r->l), t = r;
28          pull(t);
29          return t;
30      }//opcional:
31      void merge(treap t) {root = merge(root, t.root), t.root=0;}
32      //*****KEY OPERATIONS*****//
33      void splitKey(pnode t, Key key, pnode &l, pnode &r) {
34          if (!t) return void(l = r = 0);
35          push(t);
36          if (key <= t->key) splitKey(t->l, key, l, t->l), r = t;
37          else splitKey(t->r, key, t->r, r), l = t;
38          pull(t);
39      }
40      void insertKey(Key key) {
41          pnode elem = new node(key, rand());
42          pnode t1, t2; splitKey(root, key, t1, t2);
43          t1=merge(t1,elem);
44          root=merge(t1,t2);
45      }
46      void eraseKeys(Key key1, Key key2) {
47          pnode t1,t2,t3;
48          splitKey(root,key1,t1,t2);
49          splitKey(t2,key2, t2, t3);
50          root=merge(t1,t3);
51      }
52      void eraseKey(pnode &t, Key key) {
53          if (!t) return;
54          push(t);
55          if (key == t->key) t=merge(t->l, t->r);
56          else if (key < t->key) eraseKey(t->l, key);
57          else eraseKey(t->r, key);
58          pull(t);
59      }
60      void eraseKey(Key key) {eraseKey(root, key);}
61      pnode findKey(pnode t, Key key) {
62          if (!t) return 0;
63          if (key == t->key) return t;
64          if (key < t->key) return findKey(t->l, key);
65          return findKey(t->r, key);
66      }
67      pnode findKey(Key key) { return findKey(root, key); }
68      //*****POS OPERATIONS*****// No mezclar con las funciones Key
69      //(No funciona con pos:)
70      void splitSize(pnode t, int sz, pnode &l, pnode &r) {
71          if (!t) return void(l = r = 0);
72          push(t);
73          if (sz <= size(t->l)) splitSize(t->l, sz, l, t->l), r = t;
74          else splitSize(t->r, sz - 1 - size(t->l), t->r, r), l = t;
75          pull(t);
76      }
77      void insertPos(int pos, Key key) {
78          pnode elem = new node(key, rand());
79          pnode t1,t2; splitSize(root, pos, t1, t2);
80          t1=merge(t1,elem);
```

```
81        root=merge(t1,t2);
82      }
83      void erasePos(int pos1, int pos2=-1) {
84      if(pos2==-1) pos2=pos1+1;
85          pnode t1,t2,t3;
86          splitSize(root,pos1,t1,t2);
87          splitSize(t2,pos2-pos1,t2,t3);
88          root=merge(t1, t2);
89      }
90      pnode findPos(pnode t, int pos) {
91          if(!t) return 0;
92          if(pos <= size(t->l)) return findPos(t->l, pos);
93          return findPos(t->r, pos - 1 - size(t->l));
94      }
95      Key &operator[](int pos){return findPos(root, pos)->key;}//ojito
96  };
```

2.11. Gain-Cost Set

```
1  //esta estructura mantiene pairs(beneficio, costo)
2  //de tal manera que en el set quedan ordenados
3  //por beneficio Y COSTO creciente. (va borrando los que no son optimos)
4  struct V{
5    int gain, cost;
6    bool operator<(const V &b)const{return gain<b.gain;}
7  };
8  set<V> s;
9  void add(V x){
10   set<V>::iterator p=s.lower_bound(x);//primer elemento mayor o igual
11   if(p!=s.end() && p->cost <= x.cost) return;//ya hay uno mejor
12   p=s.upper_bound(x);//primer elemento mayor
13   if(p!=s.begin()){//borro todos los peores (<=beneficio  y >=costo)
14     --p;//ahora es ultimo elemento menor o igual
15     while(p->cost >= x.cost){
16       if(p==s.begin()){s.erase(p); break;}
17       s.erase(p--);
18     }
19   }
20   s.insert(x);
21  }
22  int get(int gain){//minimo costo de obtener tal ganancia
23    set<V>::iterator p=s.lower_bound((V){gain, 0});
24    return p==s.end()? INF : p->cost;}
```

3. Algos

3.1. Longest Increasing Subsecuence

```
1  //Para non-increasing, cambiar comparaciones y revisar busq binaria
2  //Given an array, paint it in the least number of colors so that each
       color turns to a non-increasing subsequence.
3  //Solution:Min number of colors=Length of the longest increasing
       subsequence
4  int N, a[MAXN];//secuencia y su longitud
5  ii d[MAXN+1];//d[i]=ultimo valor de la subsecuencia de tamanio i
6  int p[MAXN];//padres
7  vector<int> R;//respuesta
8  void rec(int i){
9    if(i==-1) return;
10   R.push_back(a[i]);
11   rec(p[i]);
12  }
13  int lis(){//O(nlogn)
14    d[0] = ii(-INF, -1); forn(i, N) d[i+1]=ii(INF, -1);
15    forn(i, N){
16      int j = upper_bound(d, d+N+1, ii(a[i], INF))-d;
17      if (d[j-1].first < a[i]&&a[i] < d[j].first){
18        p[i]=d[j-1].second;
19        d[j] = ii(a[i], i);
20      }
21    }
22    R.clear();
23    dforn(i, N+1) if(d[i].first!=INF){
24      rec(d[i].second);//reconstruir
25      reverse(R.begin(), R.end());
26      return i;//longitud
27    }
28    return 0;
29  }
```

4. Strings

4.1. KMP

```
1  string T;//cadena donde buscar(where)
2  string P;//cadena a buscar(what)
3  int b[MAXLEN];//back table
```

```
4   void kmppre(){//by gabina with love
5       int i =0, j=-1; b[0]=-1;
6       while(i<sz(P)){
7           while(j>=0 && P[i] != P[j]) j=b[j];
8           i++, j++;
9           b[i] = j;
10      }
11  }
12
13  void kmp(){
14      int i=0, j=0;
15      while(i<sz(T)){
16          while(j>=0 && T[i]!=P[j]) j=b[j];
17          i++, j++;
18          if(j==sz(P)){
19              printf("P␣is␣found␣at␣index␣%d␣in␣T\n", i-j);
20              j=b[j];
21          }
22      }
23  }
```

4.2.   Trie

```
1   struct trie{
2     map<char, trie> m;
3     void add(const string &s, int p=0){
4       if(s[p]) m[s[p]].add(s, p+1);
5     }
6     void dfs(){
7       //Do stuff
8       forall(it, m)
9         it->second.dfs();
10    }
11  };
```

4.3.   Suffix Array (corto, nlog2n)

```
1   pair<int, int> sf[MAXN];
2   bool comp(int lhs, int rhs) {return sf[lhs] < sf[rhs];}
3   struct SuffixArray {
4     //sa guarda los indices de los sufijos ordenados
5     int sa[MAXN], r[MAXN];
6     void init(const char *a, int n) {
7         forn(i, n) r[i] = a[i];
```

```
8       for(int m = 1; m < n; m <<= 1) {
9         forn(i, n) sa[i]=i, sf[i] = make_pair(r[i], i+m<n? r[i+m]:-1);
10            stable_sort(sa, sa+n, comp);
11            r[sa[0]] = 0;
12            forr(i, 1, n) r[sa[i]]= sf[sa[i]] != sf[sa[i - 1]] ? i : r[
                  sa[i-1]];
13        }
14    }
15  } sa;
```

4.4.   Suffix Array (largo, nlogn)

```
1   #define MAX_N 1000
2   #define rBOUND(x) (x<n? r[x] : 0)
3   //sa will hold the suffixes in order.
4   int sa[MAX_N], r[MAX_N], n;
5   string s; //input string, n=sz(s)
6
7   void countingSort(int k){
8     int f[MAX_N], tmpsa[MAX_N];
9     zero(f);
10    forn(i, n) f[rBOUND(i+k)]++;
11    int sum=0;
12    forn(i, max(255, n)){
13      int t=f[i]; f[i]=sum; sum+=t;}
14    forn(i, n)
15      tmpsa[f[rBOUND(sa[i]+k)]++]=sa[i];
16    memcpy(sa, tmpsa, sizeof(sa));
17  }
18  void constructsa(){//O(n log n)
19    n=sz(s);
20    forn(i, n) sa[i]=i, r[i]=s[i];
21    for(int k=1; k<n; k<<=1){
22      countingSort(k), countingSort(0);
23      int rank, tmpr[MAX_N];
24      tmpr[sa[0]]=rank=0;
25      forr(i, 1, n)
26        tmpr[sa[i]]=(r[sa[i]]==r[sa[i-1]] && r[sa[i]+k]==r[sa[i-1]+k] )?
              rank : ++rank;
27      memcpy(r, tmpr, sizeof(r));
28      if(r[sa[n-1]]==n-1) break;
29    }
30  }
```

```
31  void print(){//for debug
32    forn(i, n)
33      cout << i << '␣' <<
34      s.substr(sa[i], s.find( '$', sa[i])-sa[i]) << endl;}
```

4.5. String Matching With Suffix Array

```
1  //returns (lowerbound, upperbound) of the search
2  ii stringMatching(string P){ //O(sz(P)lgn)
3    int lo=0, hi=n-1, mid=lo;
4    while(lo<hi){
5      mid=(lo+hi)/2;
6      int res=s.compare(sa[mid], sz(P), P);
7      if(res>=0) hi=mid;
8      else lo=mid+1;
9    }
10   if(s.compare(sa[lo], sz(P), P)!=0) return ii(-1, -1);
11   ii ans; ans.fst=lo;
12   lo=0, hi=n-1, mid;
13   while(lo<hi){
14     mid=(lo+hi)/2;
15     int res=s.compare(sa[mid], sz(P), P);
16     if(res>0) hi=mid;
17     else lo=mid+1;
18   }
19   if(s.compare(sa[hi], sz(P), P)!=0) hi--;
20   ans.snd=hi;
21   return ans;
22 }
```

4.6. LCP (Longest Common Prefix)

```
1  //Calculates the LCP between consecutives suffixes in the Suffix Array.
2  //LCP[i] is the length of the LCP between sa[i] and sa[i-1]
3  int LCP[MAX_N], phi[MAX_N], PLCP[MAX_N];
4  void computeLCP(){//O(n)
5    phi[sa[0]]=-1;
6    forr(i, 1, n) phi[sa[i]]=sa[i-1];
7    int L=0;
8    forn(i, n){
9      if(phi[i]==-1) {PLCP[i]=0; continue;}
10     while(s[i+L]==s[phi[i]+L]) L++;
11     PLCP[i]=L;
12     L=max(L-1, 0);
```

```
13   }
14   forn(i, n) LCP[i]=PLCP[sa[i]];
15 }
```

4.7. Corasick

```
1
2  struct trie{
3    map<char, trie> next;
4    trie* tran[256];//transiciones del automata
5    int idhoja, szhoja;//id de la hoja o 0 si no lo es
6    //link lleva al sufijo mas largo, nxthoja lleva al mas largo pero que
         es hoja
7    trie *padre, *link, *nxthoja;
8    char pch;//caracter que conecta con padre
9    trie(): tran(),  idhoja(), padre(), link() {}
10   void insert(const string &s, int id=1, int p=0){//id>0!!!
11     if(p<sz(s)){
12       trie &ch=next[s[p]];
13       tran[(int)s[p]]=&ch;
14       ch.padre=this, ch.pch=s[p];
15       ch.insert(s, id, p+1);
16     }
17     else idhoja=id, szhoja=sz(s);
18   }
19   trie* get_link() {
20     if(!link){
21       if(!padre) link=this;//es la raiz
22       else if(!padre->padre) link=padre;//hijo de la raiz
23       else link=padre->get_link()->get_tran(pch);
24     }
25     return link;
26   }
27   trie* get_tran(int c) {
28     if(!tran[c])
29       tran[c] = !padre? this : this->get_link()->get_tran(c);
30     return tran[c];
31   }
32   trie *get_nxthoja(){
33     if(!nxthoja) nxthoja = get_link()->idhoja? link : link->nxthoja;
34     return nxthoja;
35   }
36   void print(int p){
```

```
37      if(idhoja)
38        cout << "found " << idhoja << "  at position " << p-szhoja << endl
              ;
39      if(get_nxthoja()) get_nxthoja()->print(p);
40    }
41    void matching(const string &s, int p=0){
42      print(p);
43      if(p<sz(s)) get_tran(s[p])->matching(s, p+1);
```

5.   Geometría

#define EPS 1e-9

5.1.   Punto

```
1  struct pto{
2    tipo x, y;
3    pto(tipo x=0, tipo y=0):x(x),y(y){}
4    pto operator+(pto a){return pto(x+a.x, y+a.y);}
5    pto operator-(pto a){return pto(x-a.x, y-a.y);}
6    pto operator+(tipo a){return pto(x+a, y+a);}
7    pto operator*(tipo a){return pto(x*a, y*a);}
8    pto operator/(tipo a){return pto(x/a, y/a);}
9    //dot product, producto interno:
10   tipo operator*(pto a){return x*a.x+y*a.y;}
11   //module of the cross product or vectorial product:
12   //if a is less than 180 clockwise from b, a^b>0
13   tipo operator^(pto a){return x*a.y-y*a.x;}
14   //returns true if this is at the left side of line qr
15   bool left(pto q, pto r){return ((q-*this)^(r-*this))>0;}
16   bool operator<(const pto &a) const{return x<a.x || (abs(x-a.x)<EPS &&
        y<a.y);}
17 bool operator==(pto a){return abs(x-a.x)<EPS && abs(y-a.y)<EPS;}
18   double norm(){return sqrt(x*x+y*y);}
19   tipo norm_sq(){return x*x+y*y;}
20 };
21 double dist(pto a, pto b){return (b-a).norm();}
22 typedef pto vec;
23
24 double angle(pto a, pto o, pto b){
25   vec oa=a-o, ob=b-o;
26   return acos((oa*ob) / sqrt(oa.norm_sq()*ob.norm_sq()));}
27
```

```
28 //rotate p by theta rads CCW w.r.t. origin (0,0)
29 pto rotate(pto p, double theta){
30    return pto(p.x*cos(theta)-p.y*sin(theta),
31      p.x*sin(theta)+p.y*cos(theta));
32 }
```

5.2.   Line

```
1  struct line{
2    line() {}
3    double a,b,c;//Ax+By=C
4  //pto MUST store float coordinates!
5    line(double a, double b, double c):a(a),b(b),c(c){}
6    line(pto p, pto q): a(q.y-p.y), b(p.x-q.x), c(a*p.x+b*p.y) {}
7  };
8  bool parallels(line l1, line l2){return abs(l1.a*l2.b-l2.a*l1.b)<EPS;}
9  pto inter(line l1, line l2){//intersection
10   double det=l1.a*l2.b-l2.a*l1.b;
11   if(abs(det)<EPS) return pto(INF, INF);//parallels
12   return pto(l2.b*l1.c-l1.b*l2.c, l1.a*l2.c-l2.a*l1.c)/det;
13 }
```

5.3.   Segment

```
1  struct segm{
2    pto s,f;
3    segm(pto s, pto f):s(s), f(f) {}
4    pto closest(pto p) {//use for dist to point
5      double l2 = dist_sq(s, f);
6      if(l2==0.) return s;
7      double t =((p-s)*(f-s))/l2;
8      if (t<0.) return s;//not write if is a line
9      else if(t>1.)return f;//not write if is a line
10     return s+((f-s)*t);
11   }
12   bool inside(pto p){
13 return ((s-p)^(f-p))==0 && min(s, f)<*this&&*this<max(s, f);}
14 };
15
16 bool insidebox(pto a, pto b, pto p) {
17   return (a.x-p.x)*(p.x-b.x)>-EPS && (a.y-p.y)*(p.y-b.y)>-EPS;
18 }
19 pto inter(segm s1, segm s2){
20   pto r=inter(line(s1.s, s1.f), line(s2.s, s2.f));
```

```
21    if(insidebox(s1.s,s1.f,p) && insidebox(s2.s,s2.f,p))
22        return r;
23    return pto(INF, INF);
24 }
```

5.4. Rectangle

```
1  struct rect{
2    //lower-left and upper-right corners
3    pto lw, up;
4  };
5  //returns if there's an intersection and stores it in r
6  bool inter(rect a, rect b, rect &r){
7    r.lw=pto(max(a.lw.x, b.lw.x), max(a.lw.y, b.lw.y));
8    r.up=pto(min(a.up.x, b.up.x), min(a.up.y, b.up.y));
9    //check case when only a edge is common
10   return r.lw.x<r.up.x && r.lw.y<r.up.y;
11 }
```

5.5. Polygon Area

```
1  double area(vector<tipo> &p){//O(sz(p))
2    double area=0;
3    forn(i, sz(p)) area+=p[i]^p[(i+1)%sz(p)];
4    //if points are in clockwise order then area is negative
5    return abs(area)/2;
6  }
7  //Area ellipse = M_PI*a*b where a and b are the semi axis lengths
8  //Area triangle = sqrt(s*(s-a)(s-b)(s-c)) where s=(a+b+c)/2
```

5.6. Circle

```
1  vec perp(vec v){return vec(-v.y, v.x);}
2  line bisector(pto x, pto y){
3    line l=line(x, y); pto m=(x+y)/2;
4    return line(-l.b, l.a, -l.b*m.x+l.a*m.y);
5  }
6  struct Circle{
7    pto o;
8    double r;
9  //circle determined by three points, uses line
10   Circle(pto x, pto y, pto z){
11     o=inter(bisector(x, y), bisector(y, z));
12     r=dist(o, x);
```

```
13   }
14   pair<pto, pto> ptosTang(pto p){
15     pto m=(p+o)/2;
16     tipo d=dist(o, m);
17     tipo a=r*r/(2*d);
18     tipo h=sqrt(r*r-a*a);
19     pto m2=o+(m-o)*a/d;
20     vec per=perp(m-o)/d;
21     return mkp(m2-per*h, m2+per*h);
22   }
23 };
24 //finds the center of the circle containing p1 and p2 with radius r
25 //as there may be two solutions swap p1, p2 to get the other
26 bool circle2PtsRad(pto p1, pto p2, double r, pto &c){
27     double d2=(p1-p2).norm_sq(), det=r*r/d2-0.25;
28     if(det<0) return false;
29     c=(p1+p2)/2+perp(p2-p1)*sqrt(det);
30     return true;
31 }
```

5.7. Point in Poly

```
1  //checks if v is inside of P, using ray casting
2  //works with convex and concave.
3  //excludes boundaries, handle it separately using segment.inside()
4  bool inPolygon(pto v, vector<pto>& P) {
5    bool c = false;
6    forn(i, sz(P)){
7      int j=(i+1)%sz(P);
8      if((P[j].y>v.y) != (P[i].y > v.y) &&
9      (v.x < (P[i].x - P[j].x) * (v.y-P[j].y) / (P[i].y - P[j].y) + P[j].x))
10       c = !c;
11   }
12   return c;
13 }
```

5.8. Convex Check CHECK

```
1  bool isConvex(vector<int> &p){//O(N)
2    int N=sz(p);
3    if(N<3) return false;
4    bool isLeft=p[0].left(p[1], p[2]);
5    forr(i, 1, N)
6      if(p[i].left(p[(i+1)%N], p[(i+2)%N])!=isLeft)
```

```
7       return false;
8     return true; }
```

5.9. Convex Hull

```
1  //stores convex hull of P in S, CCW order
2  void CH(vector<pto>& P, vector<pto> &S){
3    S.clear();
4    sort(P.begin(), P.end());
5    forn(i, sz(P)){
6      while(sz(S)>= 2 && S[sz(S)-1].left(S[sz(S)-2], P[i])) S.pop_back();
7      S.pb(P[i]);
8    }
9    S.pop_back();
10   int k=sz(S);
11   dforn(i, sz(P)){
12     while(sz(S) >= k+2 && S[sz(S)-1].left(S[sz(S)-2], P[i])) S.pop_back
             ();
13     S.pb(P[i]);
14   }
15   S.pop_back();
16 }
```

5.10. Cut Polygon

```
1  //cuts polygon Q along the line ab
2  //stores the left side (swap a, b for the right one) in P
3  void cutPolygon(pto a, pto b, vector<pto> Q, vector<pto> &P){
4    P.clear();
5    forn(i, sz(Q)){
6      double left1=(b-a)^(Q[i]-a), left2=(b-a)^(Q[(i+1)%sz(Q)]-a);
7      if(left1>=0) P.pb(Q[i]);
8      if(left1*left2<0)
9        P.pb(inter(line(Q[i], Q[(i+1)%sz(Q)]), line(a, b)));
10   }
11 }
```

5.11. Bresenham

```
1  //plot a line approximation in a 2d map
2  void bresenham(pto a, pto b){
3    pto d=b-a; d.x=abs(d.x), d.y=abs(d.y);
4    pto s(a.x<b.x? 1: -1, a.y<b.y? 1: -1);
5    int err=d.x-d.y;
```

```
6    while(1){
7      m[a.x][a.y]=1;//plot
8      if(a==b) break;
9      int e2=2*err;
10     if(e2 > -d.y){
11       err-=d.y, a.x+=s.x;
12     if(e2 < d.x)
13       err+= d.x, a.y+= s.y;
14   }
15 }
```

5.12. Rotate Matrix

```
1  //rotates matrix t 90 degrees clockwise
2  //using auxiliary matrix t2(faster)
3  void rotate(){
4    forn(x, n) forn(y, n)
5      t2[n-y-1][x]=t[x][y];
6    memcpy(t, t2, sizeof(t));
7  }
```

6. Math

6.1. Sumatorias

$$\sum_{i=m}^{n} i = \frac{n(n+1)}{2} - \frac{m(m-1)}{2} = \frac{(n+1-m)(n+m)}{2}$$

$$\sum_{i=0}^{n} i = \sum_{i=1}^{n} i = \frac{n(n+1)}{2}$$

$$\sum_{i=0}^{n} i^2 = \frac{n(n+1)(2n+1)}{6} = \frac{n^3}{3} + \frac{n^2}{2} + \frac{n}{6}$$

$$\sum_{i=0}^{n} i(i-1) = \frac{8}{6}\left(\frac{n}{2}\right)\left(\frac{n}{2}+1\right)(n+1)$$

(doubles) $\rightarrow$ Sino ver caso impar y par

$$\sum_{i=0}^{n} i^3 = \left(\frac{n(n+1)}{2}\right)^2 = \frac{n^4}{4} + \frac{n^3}{2} + \frac{n^2}{4} = \left[\sum_{i=1}^{n} i\right]^2$$

$$\sum_{i=0}^{n} i^4 = \frac{n(n+1)(2n+1)(3n^2+3n-1)}{30} = \frac{n^5}{5} + \frac{n^4}{2} + \frac{n^3}{3} - \frac{n}{30}$$

$$\sum_{i=0}^{n} i^p = \frac{(n+1)^{p+1}}{p+1} + \sum_{k=1}^{p} \frac{B_k}{p-k+1} \binom{p}{k} (n+1)^{p-k+1}$$

6.2. Combinatorio

```
forn(i, MAXN+1){//comb[i][k]=i tomados de a k
  comb[i][0]=comb[i][i]=1;
  forr(k, 1, i) comb[i][k]=(comb[i-1][k]+comb[i-1][k-1])%MOD;
}
```

6.3. Exp. de Numeros Mod.

```
int expmod (int b, int e){
  if(!e) return 1;
  ll q= expmod(b,e/2); q=(q*q)%MOD;
  return e%2? (b * q)%MOD : q;
}
```

6.4. Exp. de Matrices y Fibonacci en log(n)

```
struct M22{          // |a b|
  tipo a,b,c,d;// |c d|
  M22 operator*(const M22 &p) const {
    return (M22){a*p.a+b*p.c, a*p.b+b*p.d, c*p.a+d*p.c,c*p.b+d*p.d};}
};
M22 operator^(const M22 &p, int n){
  if(!n) return (M22){1, 0, 0, 1};//identidad
  M22 q=p^(n/2); q=q*q;
  return n%2? p * q : q;}

ll fibo(ll n){//calcula el fibonacci enesimo
  M22 mat=(M22){0, 1, 1, 1}^n;
  return mat.a*f0+mat.b*f1;//f0 y f1 son los valores iniciales
}
```

6.5. Funciones de primos

```
ll numPrimeFactors (ll n){
  ll rta = 0;
  map<ll,ll> f=fact(n);
  forall(it, f) rta += it->second;
  return rta;
}
```

```
ll numDiffPrimeFactors (ll n){
  ll rta = 0;
  map<ll,ll> f=fact(n);
  forall(it, f) rta += 1;
  return rta;
}

ll sumPrimeFactors (ll n){
  ll rta = 0;
  map<ll,ll> f=fact(n);
  forall(it, f) rta += it->first;
  return rta;
}

ll numDiv (ll n){
  ll rta = 1;
  map<ll,ll> f=fact(n);
  forall(it, f) rta *= (it->second + 1);
  return rta;
}

ll sumDiv (ll n){
  ll rta = 1;
  map<ll,ll> f=fact(n);
  forall(it, f) rta *= ((ll)pow((double)it->first, it->second + 1.0)-1)
      / (it->first-1);
  return rta;
}

ll eulerPhi (ll n){
  ll rta = n;
  map<ll,ll> f=fact(n);
  forall(it, f) rta -= rta / it->first;
  return rta;
}
```

6.6. Phollard's Rho

```
ll mulmod (ll a, ll b, ll c) { //returns (a*b)%c, and minimize overfloor
  ll x = 0, y = a%c;
  while (b > 0){
    if (b % 2 == 1) x = (x+y) % c;
    y = (y*2) % c;
```

```cpp
6       b /= 2;
7     }
8     return x % c;
9   }
10
11  ll pollard_rho (ll n){
12    int i = 0, k = 2;
13    ll x = 3, y = 3;
14    while (1){
15      i++;
16      x = (mulmod (x,x,n) + n - 1) % n;
17      ll d = gcd (abs(y-x), n);
18      if (d != 1 && d != n) return d;
19      if (i == k) y = x, k*=2;
20    }
21  }
22
23  int main(){
24    ll n = 2063512844981574047LL;
25    ll ans = pollard_rho (n);
26    if (ans > n / ans) ans = n / ans;
27    printf ("%lld %lld\n", ans, n / ans);
28      return 0;
29  }
```

6.7. Criba

```cpp
1   #define MAXP 80000  //no necesariamente primo
2   int criba[MAXP+1];
3   vector<int> primos;
4   void buscarprimos(){
5     int sq=sqrt(MAXP)+1;
6     forr(p, 2, MAXP+1) if(!criba[p]){
7       primos.push_back(p);
8       if(p<=sq)
9         for(int m=p*p; m<=MAXP; m+=p)//borro los multiplos de p
10          if(!criba[m])criba[m]=p;
11    }
12  }
```

6.8. Factorizacion

Sea $n = \prod p_i^{k_i}$, fact(n) genera un map donde a cada p_i le asocia su k_i

```cpp
1   //factoriza bien numeros hasta (maximo primo)^2
```

```cpp
2   map<ll,ll> fact(ll n){
3     map<ll,ll> ret;
4     forall(p, primos){
5       while(!(n%*p)){
6         ret[*p]++;//divisor found
7         n/=*p;
8       }
9     }
10    if(n>1) ret[n]++;
11    return ret;
12  }
```

6.9. GCD

```cpp
1   tipo gcd(tipo a, tipo b){return a?gcd(b %a, a):b;}
```

6.10. LCM

```cpp
1   tipo lcm(tipo a, tipo b){return a / gcd(a,b) * b;}
```

6.11. Simpson

```cpp
1   double integral(double a, double b, int n=10000) {//O(n), n=cantdiv
2     double area=0, h=(b-a)/n, fa=f(a), fb;
3     forn(i, n){
4       fb=f(a+h*(i+1));
5       area+=fa+ 4*f(a+h*(i+0.5)) +fb, fa=fb;
6     }
7     return area*h/6.;}
```

6.12. Fraction

```cpp
1   struct frac{
2     tipo p,q;
3     frac(tipo p=0, tipo q=1):p(p),q(q) {norm();}
4     tipo mcd(tipo a, tipo b){return a?mcd(b %a, a):b;}
5     void norm(){
6       tipo a = mcd(p,q);
7       if(a) p/=a, q/=a;
8       else q=1;
9       if (q<0) q=-q, p=-p;}
10    frac operator+(const frac& o){
11      tipo a = mcd(q,o.q);
```

```
12      return frac(p*(o.q/a)+o.p*(q/a), q*(o.q/a));}
13    frac operator-(const frac& o){
14      tipo a = mcd(q,o.q);
15      return frac(p*(o.q/a)-o.p*(q/a), q*(o.q/a));}
16    frac operator*(frac o){
17      tipo a = mcd(q,o.p), b = mcd(o.q,p);
18      return frac((p/b)*(o.p/a), (q/a)*(o.q/b));}
19    frac operator/(frac o){
20      tipo a = mcd(q,o.q), b = mcd(o.p,p);
21      return frac((p/b)*(o.q/a),(q/a)*(o.p/b));}
22    bool operator<(const frac &o) const{return p*o.q < o.p*q;}
23    bool operator==(frac o){return p==o.p&&q==o.q;}
24 };
```

6.13. Polinomio

```
1  #define MAX_GR  20
2  struct poly {
3    tipo p[MAX_GR];//guarda los coeficientes del polinomio
4    poly(){zero(p);}
5    int gr(){//calculates grade of the polynomial
6      dforn(i,MAX_GR) if(p[i]) return i;
7      return 0; }
8    bool isnull() {return gr()==0 && !p[0];}
9    poly operator+(poly b) {// - is analogous
10     poly c=THIS;
11     forn(i,MAX_GR) c.p[i]+=b.p[i];
12     return c;
13   }
14   poly operator*(poly b) {
15     poly c;
16     forn(i,MAX_GR) forn(k,i+1) c.p[i]+=p[k]*b.p[i-k];
17     return c;
18   }
19   tipo eval(tipo v) {
20     tipo sum = 0;
21     dforn(i, MAX_GR) sum=sum*v + p[i];
22     return sum;
23   }
24   //the following function generates the roots of the polynomial
25 //it can be easily modified to return float roots
26   set<tipo> roots(){
27     set<tipo> roots;
28     tipo a0 = abs(p[0]), an = abs(p[gr()]);
29     vector<tipo> ps,qs;
30     forr(p,1,sqrt(a0)+1) if (a0%p==0) ps.pb(p),ps.pb(a0/p);
31     forr(q,1,sqrt(an)+1) if (an%q==0) qs.pb(q),qs.pb(an/q);
32     forall(pt,ps)
33       forall(qt,qs) if ( (*pt) % (*qt)==0 ) {
34         tipo root = abs((*pt) / (*qt));
35         if (eval(root)==0) roots.insert(root);
36       }
37     return roots;
38   }
39 };
40 //the following functions allows parsing an expression like
41 //34+150+4*45
42 //into a polynomial(el numero en funcion de la base)
43 #define LAST(s) (sz(s)? s[sz(s)-1] : 0)
44 #define POP(s) s.erase(--s.end());
45 poly D(string &s) {
46   poly d;
47   for(int i=0; isdigit(LAST(s)); i++) d.p[i]=LAST(s)-'0', POP(s);
48   return d;}
49
50 poly T(string &s) {
51   poly t=D(s);
52   if (LAST(s)=='*'){POP(s); return T(s)*t;}
53   return t;
54 }
55 //main function, call this to parse
56 poly E(string &s) {
57   poly e=T(s);
58   if (LAST(s)=='+'){POP(s); return E(s)+e;}
59   return e;
60 }
```

7. Grafos

7.1. Dijkstra

```
1  #define INF 1e9
2  int N;
3  #define MAX_V 250001
4  vector<ii> G[MAX_V];
5  //To add an edge use
```

```
6  #define add(a, b, w) G[a].pb(mkp(w, b))
7
8  ll dijkstra(int s, int t){//O(|E| log |V|)
9    priority_queue<ii, vector<ii>, greater<ii> > Q;
10   vector<ll> dist(N, INF); vector<int> dad(N, -1);
11   Q.push(mkp(0, s)); dist[s] = 0;
12   while(sz(Q)){
13     ii p = Q.top(); Q.pop();
14     if(p.snd == t) break;
15     forall(it, G[p.snd])
16       if(dist[p.snd]+it->first < dist[it->snd]){
17         dist[it->snd] = dist[p.snd] + it->fst;
18         dad[it->snd] = p.snd;
19         Q.push(mkp(dist[it->snd], it->snd));
20       }
21   }
22   return dist[t];
23   if(dist[t]<INF)//path generator
24     for(int i=t; i!=-1; i=dad[i])
25       printf("%d%c", i, (i==s?'\n':' '));
26 }
```

7.2. Bellman-Ford

```
1  vector<ii> G[MAX_N];//ady. list with pairs (weight, dst)
2  int dist[MAX_N];
3  void bford(int src){//O(VE)
4    dist[src]=0;
5    forn(i, N-1) forn(j, N) if(dist[j]!=INF) forall(it, G[j])
6      dist[it->snd]=min(dist[it->snd], dist[j]+it->fst);
7  }
8
9  bool hasNegCycle(){
10   forn(j, N) if(dist[j]!=INF) forall(it, G[j])
11     if(dist[it->snd]>dist[j]+it->fst) return true;
12   //inside if: all points reachable from it->snd will have -INF distance
          (do bfs)
13   return false;
14 }
```

7.3. Floyd-Warshall

```
1  //G[i][j] contains weight of edge (i, j) or INF
2  //G[i][i]=0
```

```
3  int G[MAX_N][MAX_N];
4  void floyd(){//O(N^3)
5  forn(k, N) forn(i, N) if(G[i][k]!=INF) forn(j, N) if(G[k][j]!=INF)
6    G[i][j]=min(G[i][j], G[i][k]+G[k][j]);
7  }
8  bool inNegCycle(int v){
9    return G[v][v]<0;}
10 //checks if there's a neg. cycle in path from a to b
11 bool hasNegCycle(int a, int b){
12   forn(i, N) if(G[a][i]!=INF && G[i][i]<0 && G[i][b]!=INF)
13     return true;
14   return false;
15 }
```

7.4. Kruskal

```
1  struct Ar{int a,b,w;};
2  bool operator<(const Ar& a, const Ar &b){return a.w<b.w;}
3  vector<Ar> E;
4  ll kruskal(){
5      ll cost=0;
6      sort(E.begin(), E.end());//ordenar aristas de menor a mayor
7      uf.init(n);
8      forall(it, E){
9          if(uf.comp(it->a)!=uf.comp(it->b)){//si no estan conectados
10             uf.unir(it->a, it->b);//conectar
11             cost+=it->w;
12         }
13     }
14     return cost;
15 }
```

7.5. Prim

```
1  bool taken[MAXN];
2  priority_queue<ii, vector<ii>, greater<ii> > pq;//min heap
3  void process(int v){
4      taken[v]=true;
5      forall(e, G[v])
6          if(!taken[e->second]) pq.push(*e);
7  }
8
9  ll prim(){
10     zero(taken);
```

```
11      process(0);
12      ll cost=0;
13      while(sz(pq)){
14          ii e=pq.top(); pq.pop();
15          if(!taken[e.second]) cost+=e.first, process(e.second);
16      }
17      return cost;
18  }
```

7.6. 2-SAT + Tarjan SCC

```
1  //We have a vertex representing a var and other for his negation.
2  //Every edge stored in G represents an implication. To add an equation
        of the form a||b, use addor(a, b)
3  //MAX=max cant var, n=cant var
4  #define addor(a, b) (G[neg(a)].pb(b), G[neg(b)].pb(a))
5  vector<int> G[MAX*2];
6  //idx[i]=index assigned in the dfs
7  //lw[i]=lowest index(closer from the root) reachable from i
8  int lw[MAX*2], idx[MAX*2], qidx;
9  stack<int> q;
10 int qcmp, cmp[MAX*2];
11 //verdad[cmp[i]]=valor de la variable i
12 bool verdad[MAX*2+1];
13
14 int neg(int x) { return x>=n? x-n : x+n;}
15 void tjn(int v){
16   lw[v]=idx[v]=++qidx;
17   q.push(v), cmp[v]=-2;
18   forall(it, G[v]){
19     if(!idx[*it] || cmp[*it]==-2){
20       if(!idx[*it]) tjn(*it);
21       lw[v]=min(lw[v], lw[*it]);
22     }
23   }
24   if(lw[v]==idx[v]){
25     qcmp++;
26     int x;
27     do{x=q.top(); q.pop(); cmp[x]=qcmp;}while(x!=v);
28     verdad[qcmp]=(cmp[neg(v)]<0);
29   }
30 }
31 //remember to CLEAR G!!!
```

```
32 bool satisf(){//O(n)
33   memset(idx, 0, sizeof(idx)), qidx=0;
34   memset(cmp, -1, sizeof(cmp)), qcmp=0;
35   forn(i, n){
36     if(!idx[i]) tjn(i);
37     if(!idx[neg(i)]) tjn(neg(i));
38   }
39   forn(i, n) if(cmp[i]==cmp[neg(i)]) return false;
40   return true;
41 }
```

7.7. Articulation Points

```
1  int N;
2  vector<int> G[1000000];
3  //V[i]=node number(if visited), L[i]= lowest V[i] reachable from i
4  int qV, V[1000000], L[1000000], P[1000000];
5  void dfs(int v, int f){
6    L[v]=V[v]=++qV;
7    forall(it, G[v])
8      if(!V[*it]){
9        dfs(*it, v);
10       L[v] = min(L[v], L[*it]);
11       P[v]+= L[*it]>=V[v];
12     }
13     else if(*it!=f)
14       L[v]=min(L[v], V[*it]);
15 }
16 int cantart(){ //O(n)
17   qV=0;
18   zero(V), zero(P);
19   dfs(1, 0); P[1]--;
20   int q=0;
21   forn(i, N) if(P[i]) q++;
22 return q;
23 }
```

7.8. LCA + Climb

```
1  //f[v][k] holds the 2^k father of v
2  //L[v] holds the level of v
3  int N, f[100001][20], L[100001];
4  void build(){//f[i][0] must be filled previously, O(nlgn)
5    forn(k, 20-1) forn(i, N) f[i][k+1]=f[f[i][k]][k];}
```

```
6
7    #define lg(x) (31-__builtin_clz(x))//=floor(log2(x))
8
9    int climb(int a, int d){//O(lgn)
10     if(!d) return a;
11     dforn(i, lg(L[a])+1)
12       if(1<<i<=d)
13         a=f[a][i], d-=1<<i;
14     return a;
15   }
16   int lca(int a, int b){//O(lgn)
17     if(L[a]<L[b]) swap(a, b);
18     a=climb(a, L[a]-L[b]);
19     if(a==b) return a;
20     dforn(i, lg(L[a])+1)
21       if(f[a][i]!=f[b][i])
22         a=f[a][i], b=f[b][i];
23     return f[a][0];
24   }
```

8.   Network Flow

8.1.   Dinic

```
1    int nodes, src, dest;
2    int dist[MAX], q[MAX], work[MAX];
3
4    struct Edge {
5      int to, rev;
6      ll f, cap;
7      Edge(int to, int rev, ll f, ll cap) : to(to), rev(rev), f(f), cap(cap)
            {}
8    };
9
10   vector<Edge> G[MAX];
11
12   // Adds bidirectional edge
13   void addEdge(int s, int t, ll cap){
14     G[s].push_back(Edge(t, G[t].size(), 0, cap));
15     G[t].push_back(Edge(s, G[s].size()-1, 0, 0));
16   }
17
18   bool dinic_bfs() {
```

```
19     fill(dist, dist + nodes, -1);
20     dist[src] = 0;
21     int qt = 0;
22     q[qt++] = src;
23     for (int qh = 0; qh < qt; qh++) {
24       int u = q[qh];
25       forall(e, G[u]){
26         int v = e->to;
27         if(dist[v]<0 && e->f < e->cap){
28           dist[v]=dist[u]+1;
29           q[qt++]=v;
30         }
31       }
32     }
33     return dist[dest] >= 0;
34   }
35
36   ll dinic_dfs(int u, ll f) {
37     if (u == dest) return f;
38     for (int &i = work[u]; i < (int) G[u].size(); i++) {
39       Edge &e = G[u][i];
40       if (e.cap <= e.f) continue;
41       int v = e.to;
42       if (dist[v] == dist[u] + 1) {
43         ll df = dinic_dfs(v, min(f, e.cap - e.f));
44         if (df > 0) {
45           e.f += df;
46           G[v][e.rev].f -= df;
47           return df;
48         }
49       }
50     }
51     return 0;
52   }
53
54   ll maxFlow(int _src, int _dest) {//O(V^2 E)<
55     src = _src;
56     dest = _dest;
57     ll result = 0;
58     while (dinic_bfs()) {
59       fill(work, work + nodes, 0);
60       while(ll delta = dinic_dfs(src, INF))
61         result += delta;
```

```
62      }
63      return result;
64  }
```

8.2.   Edmonds Karp's

```
1   #define MAX_V 1000
2   #define INF 1e9
3   //special nodes
4   #define SRC 0
5   #define SNK 1
6   map<int, int> G[MAX_V];//limpiar esto
7   //To add an edge use
8   #define add(a, b, w) G[a][b]=w
9   int f, p[MAX_V];
10  void augment(int v, int minE){
11      if(v==SRC) f=minE;
12      else if(p[v]!=-1){
13          augment(p[v], min(minE, G[p[v]][v]));
14          G[p[v]][v]-=f, G[v][p[v]]+=f;
15      }
16  }
17  ll maxflow(){//O(VE^2)
18      ll Mf=0;
19      do{
20          f=0;
21          char used[MAX_V]; queue<int> q; q.push(SRC);
22          zero(used), memset(p, -1, sizeof(p));
23          while(sz(q)){
24              int u=q.front(); q.pop();
25              if(u==SNK) break;
26              forall(it, G[u])
27                  if(it->snd>0 && !used[it->fst])
28                      used[it->fst]=true, q.push(it->fst), p[it->fst]=u;
29          }
30          augment(SNK, INF);
31          Mf+=f;
32      }while(f);
33      return Mf;
34  }
```

8.3.   Push-Relabel

```
1   #define MAX_V 1000
```

```
2   int N;//valid nodes are [0...N-1]
3   #define INF 1e9
4   //special nodes
5   #define SRC 0
6   #define SNK 1
7   map<int, int> G[MAX_V];
8   //To add an edge use
9   #define add(a, b, w) G[a][b]=w
10  ll excess[MAX_V];
11  int height[MAX_V], active[MAX_V], count[2*MAX_V+1];
12  queue<int> Q;
13  void enqueue(int v) {
14      if (!active[v] && excess[v] > 0) active[v]=true, Q.push(v); }
15  void push(int a, int b) {
16      int amt = min(excess[a], ll(G[a][b]));
17      if(height[a] <= height[b] || amt == 0) return;
18      G[a][b]-=amt, G[b][a]+=amt;
19      excess[b] += amt, excess[a] -= amt;
20      enqueue(b);
21  }
22  void gap(int k) {
23      forn(v, N){
24          if (height[v] < k) continue;
25          count[height[v]]--;
26          height[v] = max(height[v], N+1);
27          count[height[v]]++;
28          enqueue(v);
29      }
30  }
31  void relabel(int v) {
32      count[height[v]]--;
33      height[v] = 2*N;
34      forall(it, G[v])
35          if(it->snd)
36              height[v] = min(height[v], height[it->fst] + 1);
37      count[height[v]]++;
38      enqueue(v);
39  }
40  ll maxflow() {//O(V^3)
41      zero(height), zero(active), zero(count), zero(excess);
42      count[0] = N-1;
43      count[N] = 1;
44      height[SRC] = N;
```

```
45    active[SRC] = active[SNK] = true;
46    forall(it, G[SRC]){
47      excess[SRC] += it->snd;
48      push(SRC, it->fst);
49    }
50    while(sz(Q)) {
51      int v = Q.front(); Q.pop();
52      active[v]=false;
53    forall(it, G[v]) push(v, it->fst);
54    if(excess[v] > 0)
55      count[height[v]] == 1? gap(height[v]):relabel(v);
56    }
57    ll mf=0;
58    forall(it, G[SRC]) mf+=G[it->fst][SRC];
59    return mf;
60  }
```

9. Ayudamemoria

Límites

```
1  #include <climits> //INT_MIN, LONG_MAX, ULLONG_MAX, etc.
```

Cant. decimales

```
1  #include <iomanip>
2  cout << setprecision(2) << fixed;
```

Rellenar con espacios(para justificar)

```
1  #include <iomanip>
2  cout << setfill('␣') << setw(3) << 2 << endl;
```

Leer hasta fin de línea

```
1  #include <sstream>
2  //hacer cin.ignore() antes de getline()
3  while(getline(cin, line)){
4      istringstream is(line);
5      while(is >> X)
6        cout << X << "␣";
7      cout << endl;
8  }
```

Aleatorios

```
1  #define RAND(a, b) (rand()%(b-a+1)+a)
2  srand(time(NULL));
```

Doubles Comp.

```
1  const double EPS = 1e-9;
2  x == y  <=> fabs(x-y) < EPS
3  x >  y  <=> x > y + EPS
4  x >= y  <=> x > y - EPS
```

Límites

```
1  #include <limits>
2  numeric_limits<T>
3    ::max()
4    ::min()
5    ::epsilon()
```

Muahaha

```
1  #include <signal.h>
2  void divzero(int p){
3    while(true);}
4  void segm(int p){
5    exit(0);}
6  //in main
7  signal(SIGFPE, divzero);
8  signal(SIGSEGV, segm);
```

Mejorar velocidad

```
1  ios::sync_with_stdio(false);
```

Mejorar velocidad 2

```
1  //Solo para enteros positivos
2  inline void Scanf(int& a){
3    char c = 0;
4    while(c<33) c = getc(stdin);
5    a = 0;
6    while(c>33) a = a*10 + c - '0', c = getc(stdin);
7  }
```

Leer del teclado

```
1  freopen("/dev/tty", "a", stdin);
```

File setup

```
1  //tambien se pueden usar comas: {a, x, m, l}
2  for i in {a..k}; do cp template.cpp $i.cpp; touch $i.in; done
```